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Optoelectronic Gain Control of a Microwave Single Stage GaAs MESFET Amplifier

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OPTOELECTRONIC GAIN CONTROL OF A MICROWAVE SINGLE STAGE GaAs MESFET AMPLIFIER

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SUMMARY

In this paper we demonstrate gain control of a single stage GaAs MESFET amplifier by the use of optical illumination of photon energy greater than the GaAs bandgap. The optical illumination is supplied by a semiconductor laser diode and is coupled to the Schottky gate of the MESFET by an optical fiber. The increase in gain is observed to be as much as 5.15 dB when the MESFET is biased close to pinch-off, that is, $V_{gs} = -1.5$ V and with optical illumination of 1.5 mW.

The computed maximum available gain (MAG) and current gain ($|h_{21}|$) from the de-embedded s-parameters show that MAG is unaffected by optical illumination, however, $|h_{21}|$ increases by more than 2 dB under optical illumination of 1.5 mW. The maximum frequency of oscillation (F_{max}) and the unity current gain cutoff frequency (F_t) obtained by extrapolating the MAG and $|h_{21}|$ curves respectively show that the F_{max} is insensitive to optical illumination however F_t increases by 5 GHz.

E-3963

INTRODUCTION

Monolithic Microwave Integrated Circuit (MMIC) Technology based on the Gallium Arsenide (GaAs) Metal Semiconductor Field Effect Transistor (MESFET) has resulted in miniature receiver modules for electronically scanned phased array antenna systems (ref. 1). The basic building blocks in these modules are the low noise amplifiers, the mixers for signal downconversion to intermediate frequency (IF), the phase shifters and the variable gain amplifiers for controlling the signal phase and amplitude. For the receiver studied here, the mixer consists of a dual gate MESFET operating on the heterodyne principle and requiring a local oscillator signal. The phase shifter is of the switched line type and makes use of depletion mode MESFETs for switching. The MESFET switches are TTL compatiable and receive a 5 bit word command from a central processor for phase setting. The variable gain amplifier also consists of a dual gate MESFET which requires a variable bias voltage on the control gate for gain variation. The variable bias is provided by a D/A converter which also receivers its command from a central processor. The D/A converter consists of enhancement mode MESFETs.

The conventional approach of distributing the local oscillator and the digitial command signals to the basic blocks is to use semi-rigid coaxial cables and shielded cables respectively (ref. 2). The main disadvantage of

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this approach is that it would make the array large and heavy and offset some of the advantages gained by the monolithic technology in terms of module size and weight. An alternative approach is to use optical interconnect technique which is based on optical fiber technology and the capability to intensity-modulate an AlGaAs/GaAs semiconductor laser diode at rates up to the microwave frequencies (ref. 3). Thus the optical interconnect technique is capable of conveying the local oscillator signal to the mixer on an optical carrier. In addition, it can if necessary provide injection locking of the local osicillator to a stable master oscillator (ref. 4). In a similar manner the digital command signals to the phase shifter and to the D/A converter in the variable gain amplifiers can be transmitted from the central processor. Figure 1 presents a schematic showing possible optical interconnects in a typical phased array antenna system. Figure 2 illustrates a simple fiber optical interconnect for mircowave and digital signal distribution.

Several authors have investigated the effect of optical illumination on the dc characteristics (refs. 5 and 6) and the microwave chatacteristics (refs. 7 to 11) of GaAs MESFET's. In this paper we demonstrate for the first time gain control of a single stage GaAs MESFET amplifier by the use of optical illumination with photon energy greater than the GaAs bandgap. The optical illumination is supplied by a semiconductor laser diode and is coupled to the Schottky gate of the MESFET by an optical fiber. Thus the optical illumination has a role similar to a control gate in a dual gate MESFET. The above approach is termed direct optical gain control since optical illumination is responsible for gain variation. The amplifer operates at K-band, where NASA is developing GaAs MMICs for future satellite communications systems and NASA missions.

This paper also examines the effect of optical illumination on the figure of merit of a GaAs MESFET. The figure of merit is a good indicator of the device performance as an amplifier. Commonly used figures of merit for MESFETs are the maximum available gain (MAG) and current gain ($|h_{21}|$). These are functions of all four scattering parameters (s-parameters) of the device. Hence, the full two port s-parameters with and without optical illumination are measured for a GaAs MESFET chip device. The de-embedded s-parameters are then used to determine the effect of optical illumination on MAG, $|h_{21}|$, the maximum frequency of oscillation (F_{max}), and the unity current gain cutoff frequency (F_t).

EXPERIMENTAL SETUP

Measurements of the characteristics of an optically illuminated amplifier were carried out using a Texas Instruments chip which was based on a low-noise GaAs MESFET with a gate of length 0.25 μm and width 75 μm. The source-to-drain spacing of this device is about 1.6 to 2.0 μm, and the gate is at a distance of 0.2 to 0.3 μm from the source. The device is fabricated using molecular beam epitaxy. The amplifer consists of a single MESFET with input/output matching networks.

The GaAs MESFET investigated here was a low-noise, low-power device (DXL 0503A) manufactured by Gould, Inc. It featured a recessed Pi-gate of length

0.3 μm and width 280 μm. The source-to-drain spacing of this device is about 5 μm and the gate is centered. It is fabricated using vapor-phase epitaxy. Measurements were made to determine the effect of optical illumination on MAG, $|h_{21}|$, F_{max}, and F_t.

An AlGaAs/GaAs laser diode (SL-620, Ortel Corp.) with a fiber pigtail is used for illumination. The laser diode operates at a wavelength of 0.83 μm. The optical power emitted from the 50/125 μm multimode graded index optical fiber pigtail is about 1.5 mW. The tip of the fiber is held at a distance of 1 mm from the device.

Both the MESFET and the amplifer are mounted on alumina carriers. Details on the carriers, the coplanar waveguide (CPW) test fixture, the CPW calibration kit for de-embedding the amplifier characteristics and the device s-parameters, and the block schematic of the entire experimental setup are presented elsewhere (ref. 11).

OPTOELECTRONIC MICROWAVE AMPLIFER GAIN CONTROL

Figure 3(a) presents a photograph of the single stage GaAs MESFET amplifer which also shows the coplanar waveguide input and output lines and the biasing circuits. Figure 3(b) presents a photomicrograph of the MESFET device. Figure 3(c) presents a schematic of the amplifier circuit. The amplifer is designed to operate over a 1 GHz bandwidth centered at 26 GHz. Figures 4(a) through 4(d) show the measured s-parameters of the amplifer without optical illumination and at a fixed gate-to-source voltage of -1.19 V and drain-to-source voltage (V_{ds}) of 3 V. It should be noted that the losses occuring in the coaxial connectors, test fixture, and the input/output CPW lines have been calibrated out. Figures 5(a) through 5(d) show the measured s-parameters of the amplifer with optical illumination of 1.5 mW. Comparing figures 4 and 5 it is observed that the gain (S_{21}) increases by 2.6 dB under illumination. The increase in the gain is because of the light induced voltage which is due to the photovoltaic and photoconductive effects at the Schottky gate of the MESFET (ref. 11). The light induced voltage forward biases the gate-to-source region of the MESFET. Further, the input and output imepedances (S_{11} and S_{22}) of the amplifer show improved match to the 50 Ω input and output lines respectively. The improvement in the impedance match is because of the increase in the gate-to-source capacitance and also due to changes in the MESFET equivalent circuit element values which are brought about by optical illumination (ref. 10). Optical illumination also improves the isolation (S_{12}) between the input and output ports. This can also be attributed to the changes in the MESFET equivalent circuit element values.

The above experiments were repeated for several values of V_{gs} ranging from pinch-off to zero and at a fixed V_{ds} of 4 V. Figure 6 illustrates the increase in gain (ΔS_{21}) under illumination at the center frequency of 26 GHz and as a function of V_{gs}. ΔS_{21} is observed to take a maximum value of 5.15 dB when the MESFET is biased close to pinch-off, that is $V_{gs} = -1.5$ V. Figure 6 also illustrates the corresponding increase in the drain-to-source current ΔI_{ds} under optical illumination. ΔI_{ds} attains a maximum value of 2.89 mA when V_{gs} is close to zero, that is, $V_{gs} = -0.66$ V. Under optical illumination of 1.5 mW this translates into a responsivity of 1.93 A/W. Figure 7(a) shows the variation of the input impedance of the amplifier at the center frequency of 26 GHz with and without optical illumination as a function

of V_{gs}. Similarly, figure 7(b) shows the variation of the output impedance. These figures illustrate that the input and output impedances have improved match to 50 Ω lines, under illumination, for all bias values ranging from zero to pinch-off.

MESFET FIGURE OF MERIT UNDER OPTICAL ILLUMINATION

Maximum Available Gain and Maximum Frequency of Oscillation

The full two port scattering parameters of the MESFET chip device is measured over the frequency range 0.045 to 18 GHz with and without optical illumination. The de-embedded s-parameters are used to compute the MAG and the stability factor (K) using the EEsof Touchstone software (ref. 12). Figure 8(a) shows the MAG as a function of the frequency. Extrapolation of the MAG curve for K greater than unity at the rate of -6 dB/octave till it meets the zero gain axis yeilds F_{max}. Neither MAG or F_{max} are affected by optical illumination.

Current Gain and Unity Current Gain Cut-off Frequency

The current gain ($|h_{21}|$) is also computed from the measured s-parameters using the EEsof Touchstone software (ref. 12). Figure 8(b) shows $|h_{21}|$as a function of the frequency. Extrapolation of the $|h_{21}|$ curve at the rate of -6 dB/octave yields F_t. It is observed that optical illumination of 1.5 mW increases $|h_{21}|$ and F_t by 2 dB and 5 GHz respectively.

CONCLUSIONS AND DISCUSSIONS

This paper demonstrates for the first time optoelectronic gain control of a single stage GaAs MESFET amplifier. The gain control is achieved by illuminating the Schottky gate of the MESFET with optical power from an AlGaAs/GaAs laser diode. The measued s-parameters show that the increase in gain (S_{21}) is greater than 5 dB when the MESFET is biased close to pinch-off. Lastly, the MESFET has a responsivity of 1.93 A/W. The responsivity can be improved if the gate metallization is indium tin oxide (ITO). ITO besides being transparent also forms a good Schottky contact with GaAs and its thickness can be chosen to act as an antireflection coating at the wavelength of operation (ref. 13).

The computed MAG and $|h_{21}|$ from the deembedded s-parameters show that MAG is unaffected but that $|h_{21}|$ increases by 2 dB under optical illumination of 1.5 mW. The F_{max} and F_t obtained by extrapolating the MAG and $|h_{21}|$ curves respectively show that F_{max} is insensitive to optical illumination but Ft increases by 5 GHz. The increase in $|h_{21}|$ and F_t will result in lower switching power and smaller switching time.

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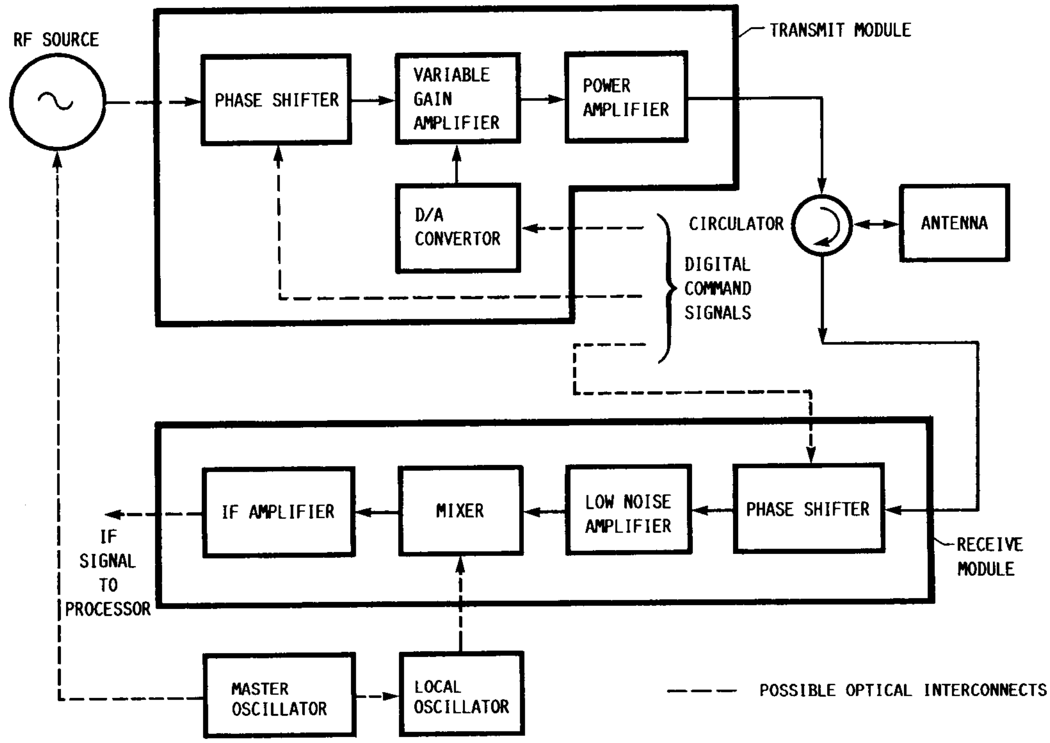


FIGURE 1. - SCHEMATIC SHOWING POSSIBLE OPTICAL INTERCONNECTS BETWEEN VARIOUS BASIC BLOCKS IN A TYPICAL PHASED ARRAY WITH GaAs MMIC BASED TRANSMIT/RECEIVE MODULES.

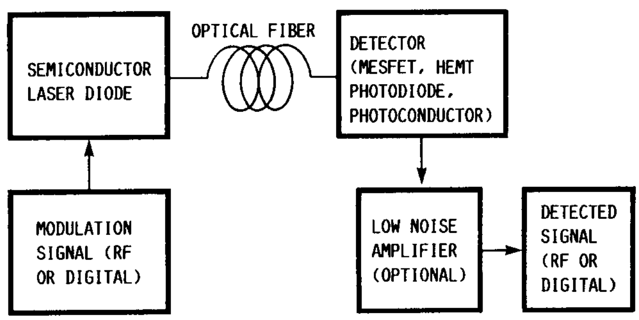
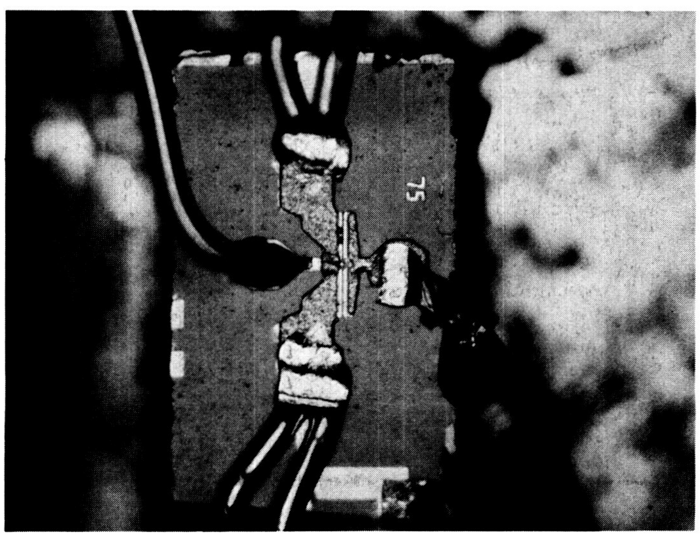


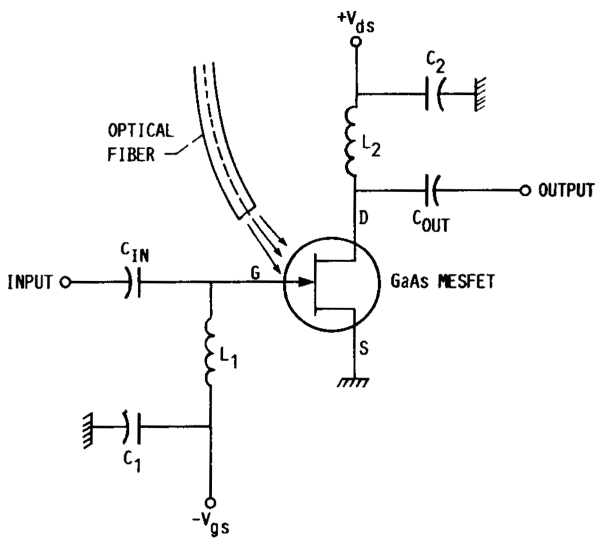
FIGURE 2. - SCHEMATIC SHOWING A TYPICAL OPTICAL INTERCONNECT FOR RF AND DIGITAL SIGNALS.

(A) PHOTOGRAPH OF AMPLIFIER.



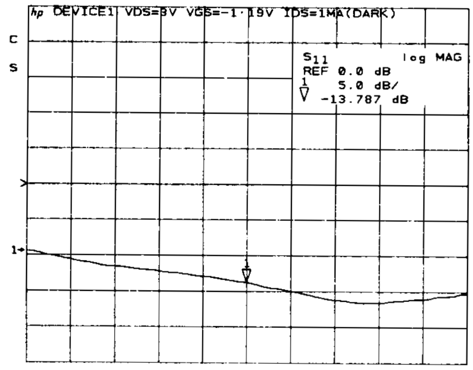
(B) PHOTOGRAPH OF THE 0.25 μm x 75 μm GaAs MESFET (TEXAS INSTRUMENTS) USED IN THE AMPLIFIER.

FIGURE 3. - GaAs MESFET AMPLIFIER.

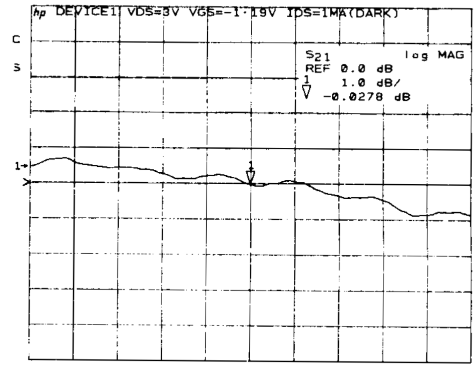


(C) CIRCUIT CONFIGURATION.

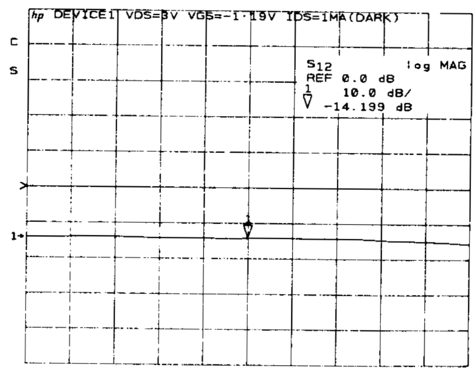
FIGURE 3. - CONCLUDED.



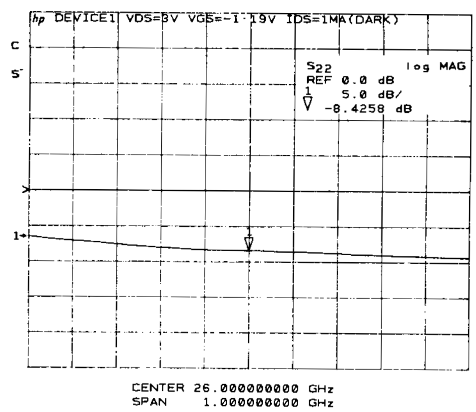
(A) S_{11}.



(B) S_{21}.

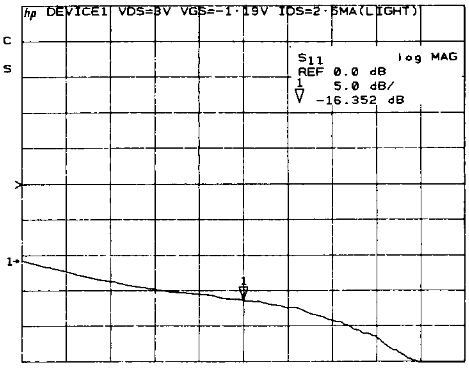


(C) S_{12}.

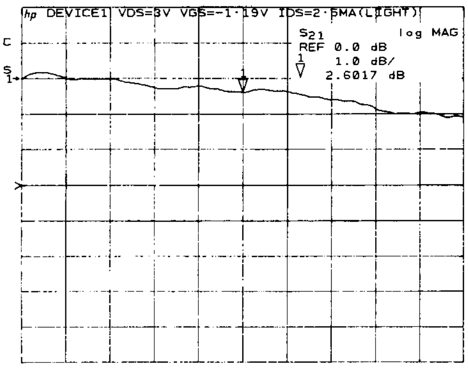


(D) S_{22}.

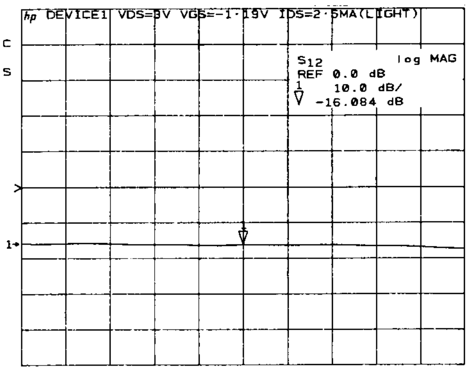
FIGURE 4. - MEASURED S-PARAMETERS AS A FUNCTION OF THE FREQUENCY OF THE AMPLIFIER WITHOUT OPTICAL ILLUMINATION.



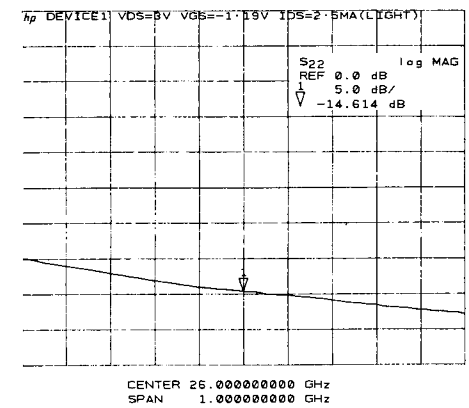
(A) S_{11}.



(B) S_{21}.



(C) S_{12}.



(D) S_{22}.

IGURE 5. - MEASURED S-PARAMETERS OF THE AMPLIFIER WHEN ILLUMINATED, AT λ = 0.83 μm AND P_{OPT} = 1.5 mW, FROM THE END OF A 50/125 μm MULTIMODE FIBER.

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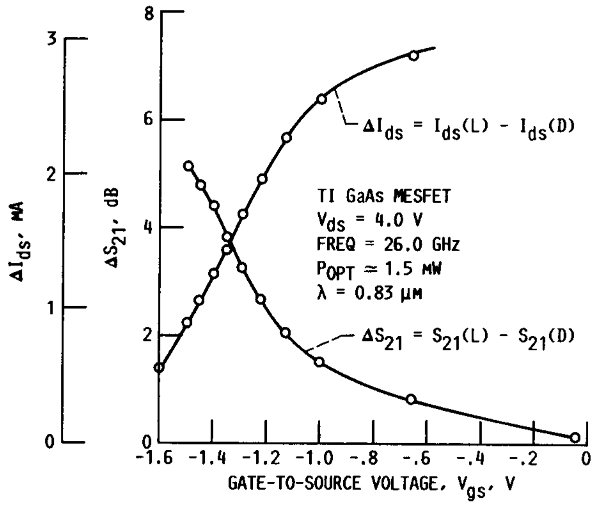
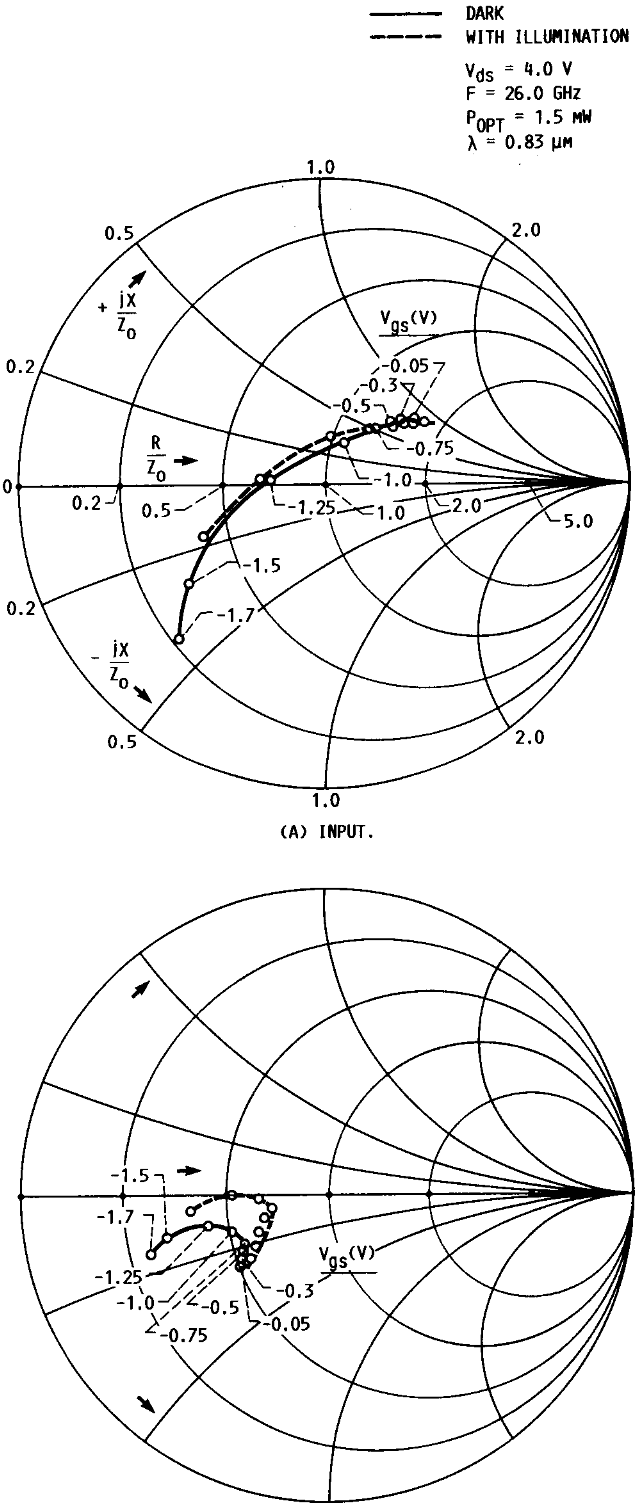
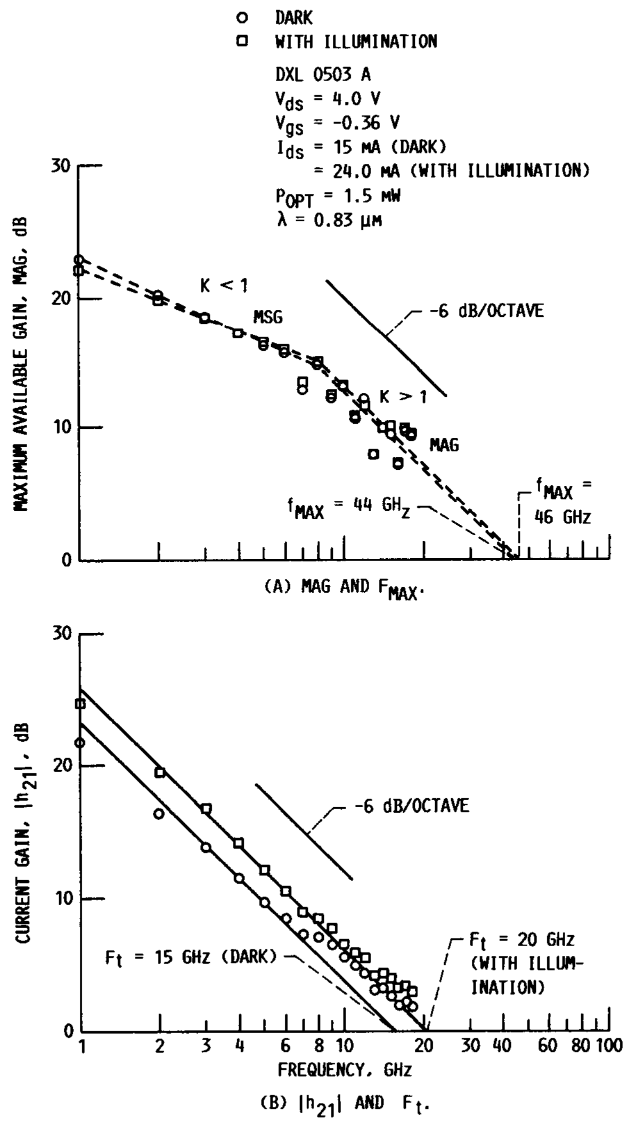


FIGURE 6. - MEASURED INCREASE IN GAIN (ΔS_{21}) AND THE DRAIN CURRENT (ΔI_{ds}) UNDER OPTICAL ILLUMINATION AS A FUNCTION OF V_{gs} AT THE CENTER FREQUENCY.



(B) OUTPUT.

FIGURE 7. - MEASURED AMPLIFIER IMPEDANCE AS A FUNCTION OF V_{gs} AT THE CENTER FREQUENCY WITH AND WITHOUT OPTICAL ILLUMINATION.



(B) $|h_{21}|$ AND F_t.

FIGURE 8. - COMPUTED FIGURE OF MERIT FROM THE DE-EMBEDDED S-PARAMETERS.

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16. Abstract

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